A Design of GNSS Based Time Management System for Telecommunication Satellite

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Abstract. Telecommunication satellites have shown the trend of network development, and the onboard payload processing and inter satellite link communication put forward higher requirements for satellite time synchronization. Taking telecommunication satellite as the application object, this paper carries out the design of GNSS (Global Navigation Satellite System) based time management system of telecommunication satellite, establishes the time management model, designs the time management system architecture, and analyzes the design strategy of time management applicable to telecommunication satellite. Furthermore, an instance of time synchronization error analysis is introduced.

Keywords: Telecommunication satellite · Time management · GNSS

1 Introduction

With the increasing demand of users for networked communication, the field of telecommunication satellite tends to develop in the direction of space-based networking, in order to improve the service quality of the system, expand the service scope of the system, and expand the business needs of users. For example, the onboard payload processing of telecommunication satellite, the establishment and maintenance of inter satellite links all have high requirements for time management. If the time synchronization error exceeds the specified range, it will cause link interruption, service discontinuity and other problems [1, 2].

Taking telecommunication satellite as the application object, this paper proposes a design method of time management system based on GNSS. Through GNSS timing, satellite bus network broadcasting, high-precision time-frequency source timing, the 1PPS (one pulse per second) time reference signal generation and so on, the satellite time management system is constructed to meet various requirements of telecommunication satellite equipment.

The remainder of this paper is structured as follows. Section 2 presents the working principle, model and system architecture of telecommunication satellite time management. In Sect. 3, we describe the operation mode and strategy design of time management. The analysis of the time synchronization error is presented in Sect. 4. We conclude in Sect. 5.

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2 Architecture of Satellite Time Management System

2.1 Time Management Working Principle

The time management function is the way to realize the time unification among constellation, whole satellite, inter satellite and satellite-ground. It realizes the time synchronization of satellite-ground and inter satellite communication of telecommunication system, and meets the requirements of time calibration and punctuality for on orbit autonomous operation.

Time synchronization is divided into absolute time synchronization and relative time synchronization. Relative time synchronization refers to the time synchronization between all nodes in the system. Absolute time synchronization refers to not only completing time synchronization in the system, but also synchronizing with coordinated universal time (UTC). The GNSS receiver provides the system time reference [3], calculates the UTC time, provides it to the whole satellite platform and payload time management equipment, and then distributes it to the satellite time users.

Satellite communication system realizes absolute time synchronization and relative time synchronization through ground time service, GNSS time service, satellite ground link, inter satellite link. Among them, ground time service and GNSS time service are absolute time synchronization means, while satellite ground link and inter satellite link are relative time synchronization means.

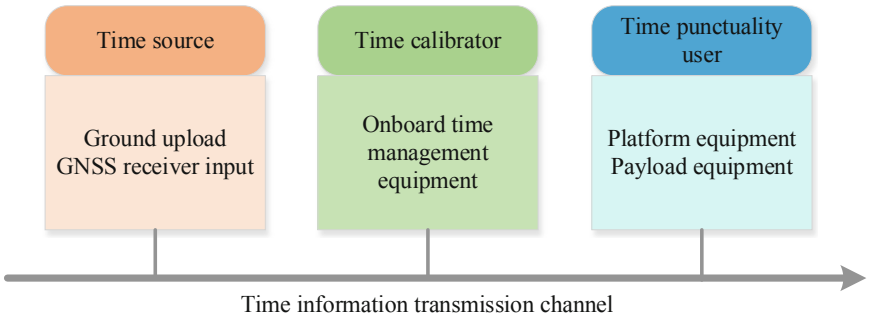

Fig. 1. Time management model

As shown in Fig. 1, the time management model of telecommunication satellite consists of four parts: time source, time calibrator, time punctuality user and time information transmission channel.

- The time source is used to initialize the time on the satellite and provide the time reference. Its input sources include the ground absolute time service telecommand upload and GNSS receiver input.
- Time calibrators provide time calibration means and correction compensation methods, including uniform time calibration, incremental time calibration and absolute time calibration. Time distribution is realized by broadcasting, point-to-point transmission with onboard time management equipment.

- The time punctuality user is the terminal application object of time information, including satellite platform equipment such as attitude and orbit control unit, payload equipment such as communication processing unit, etc.
- The time information transmission channel is used for the distribution and transmission of PPS and absolute time information, including satellite bus network such as 1553B bus and point-to-point interface such as RS422 serial data interface.

2.2 Time Management System Architecture

Figure 2 shows an architecture of time management system of telecommunication satellite. Under the normal operation mode of the satellite, the UTC time calculated by GNSS receiver is used as the time source. GNSS receiver uses high stable clock to generate 1PPS signals, and outputs two channels of 1PPS to satellite management unit and payload time unit respectively through RS422 serial data interface. The satellite management unit and the payload time unit rely on the input time information and 1PPS to trigger their own counters for time calibration and maintenance. The satellite management unit releases the time of the platform and payload time punctuality users through 1553B bus, and the payload time unit releases the time of the payload time punctuality users through RS422 serial data interface.

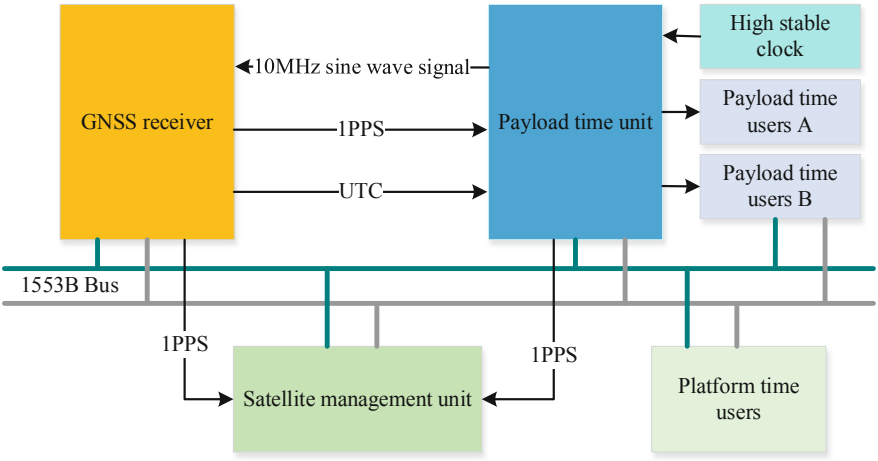

Fig. 2. Time management system architecture

3 Time Management Strategy Design

3.1 Operation Mode of Time Management

In this paper, onboard time management mainly includes two operation modes: satellite payload service operation mode based on high precision time synchronization, and satellite safe operation mode based on common precision time synchronization.

- **Satellite payload service operation mode:** GNSS receiver generates 1PPS for each time user. Within 100 ms after the 1PPS is generated, the GNSS receiver sends the time data corresponding to the 1PPS to the satellite management unit and the payload time unit through the bus and RS422 serial port respectively. When the time user receives the 1PPS, its own timer starts to subdivide the time within one second, and generates local time system according to the received time data.
- **Satellite safe operation mode:** Satellite management unit regularly distributes time information through the bus [4]. The logic of this time synchronization mechanism is simple, but it depends on the software to operate the time, which will lead to large uncertainty of time delay. If the time data is not sent successfully and needs to be resent twice, or the lower computer software is interrupted by other terminals during the processing of time, the time delay will be longer [5]. Therefore, this kind of operation mechanism is generally suitable for the application scenarios which require low accuracy of time synchronization.

3.2 Time Management Specific Design

- **Time initialization strategy:** the default initial time value of power on of satellite management unit is 0, and the ground sets the onboard time benchmark through time service telecommand. In case of software reset or shutdown, the time recovery program will be executed immediately.
- **Time calibration strategy:** according to the time source and 1PPS, the time information is sent to the satellite management unit for time calibration. The time source is divided into internal source and external source. The internal source refers to the time uploaded into the satellite by telecommand, while the external source refers to the time acquired by the satellite through GNSS receiver. The same time source is used for payload service time synchronization and platform service time synchronization.

The whole satellite timing includes GNSS timing management and ground timing. The deviation of 1PPS can be corrected by sending telecommand to adjust the phase. The ground timing includes absolute timing, incremental timing and uniform timing.

– **Absolute time calibration:** after receiving the satellite time setting telecommand from the ground, the satellite management unit sets the absolute time to the received time value.
– **Incremental timing:** after receiving the telecommand from the ground, the satellite management unit adds the received incremental value to its own time.
– **Uniform time calibration:** Each time the satellite management unit passes a time calibration interval, the onboard software will increase the absolute time of the satellite management unit by a time increment (positive or negative) that can be set by the ground telecommand.
  - **Time distribution strategy:** GNSS receiver and payload time unit generate 1PPS at each UTC integer second time. The satellite management unit counts the frequency signal output by the local clock source to generate the local time, compares it with the external time reference, outputs the reference time

according to a certain time coding format, and sends the time information to the lower computer through the bus.

- **Punctuality strategy:** the punctuality part is usually composed of time information receiving part, local time code generator. It mainly completes the receiving of time information sent by time service part, local time correction and time application. At present, the punctuality part of satellite design often exists in all terminal users in need.
- **Fault strategy:** the satellite management unit receives the 1PPS from GNSS receiver and payload time unit, and uses local clock as backup time service means to support the autonomous selection of clock source and ensure the high reliable operation of satellite time management system.

The 1PPS channel A is defined as the main signal of GNSS receiver while the channel B is defined as the backup signal. The 1PPS channel C is defined as the main signal of payload time unit while the channel D is defined as the backup signal. And the channel E is the local clock of satellite management unit. The switching strategy is as follows:

The satellite management unit identifies the time-frequency characteristics of the 1PPS. If the 1PPS is interrupted in orbit, it switches according to the priority order of channel A → B → C → D → E. Channel A, B, C and D can ensure the normal operation of satellite payload service. When the GNSS receiver is not turned on or fails to output time information and 1PPS, the satellite will adopt the common precision time synchronization mechanism. The satellite management unit will switch to rely entirely on the local clock of channel E as the time-frequency source to realize the system time synchronization and maintenance function, and ensure the safe and stable operation of the satellite platform, and in a certain period of time to maintain the operation of the satellite load. The ground can use this period of time for abnormal disposal.

In addition, if the satellite management unit is reset or cut off due to failure, the time information and important data of the satellite management unit are recovered from the platform service unit, payload service unit and other lower computers according to the preset priority, which can automatically restore the clock source use status before the failure and complete the autonomous time synchronization. If the lower computer fails to recover, the ground needs to send time service telecommand for time recovery.

4 Accuracy Analysis of Time Management

The error of time management system of telecommunication satellite is divided into hardware delay error (t_h), time transmission error (t_t), time locking error (t_l) and user timing error (t_u) [6]. As shown in Fig. 3, a time synchronization error model of telecommunication satellite should be built according to the time information transmission order of error sources. The time synchronization error of satellite could be estimated for specific time users through the whole process transmission analysis, so as to verify whether the time management accuracy meets the requirements.

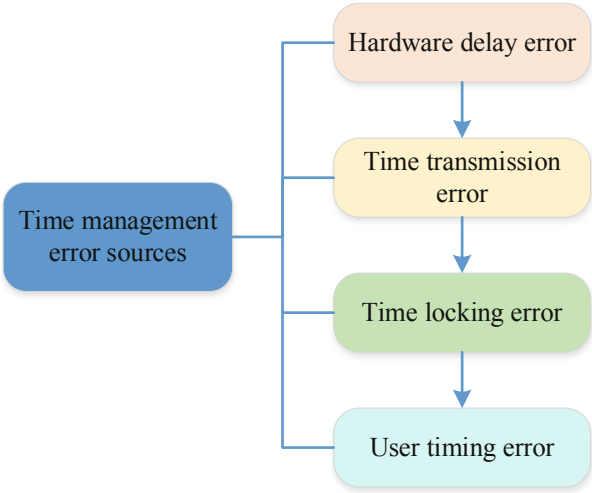

Fig. 3. Time synchronization error model

Combining the devices design and the chips user manuals, the error analysis of the operation mode of the satellite payload service based on the high-precision time synchronization is carried out. The PPS error generated by GNSS receiver is 0.5 μs. The maximum inherent transmission delay of the PPS receiving chip of the satellite management unit and the payload time unit is 40 ns, and the maximum FPGA delay of the satellite time latch is about 1μs. The maximum relative time error of satellite management unit and payload time unit is 35 μs.

The time synchronization delay characteristics are defined as follows, and the total delay T is calculated by Eq. 1).

$$T = t_h + t_t + t_l + t_u \tag{1}$$

Finally, the high-precision timing error with PPS is less than 37 μs, which meets the requirements of a telecommunication satellite payload application for time synchronization accuracy better than 40 μs.

5 Conclusion

This paper analyzes the working principle of time management based on GNSS, constructs the model and system architecture, and carries out the operating mode research and strategy design. Combined with the error theory analysis, it provides new ideas and design reference for the design of telecommunication satellite system. In the future, the experimental platform will be built to verify the design. In addition, with the development of space-based networking of telecommunication satellite system, the connotation and extension of satellite time management will be further expanded.

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